4.—Observations on stylolites in Western Australian rocks

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Abstract

Stylolites are recorded and described from limestones, dolomitic limestones, dolostone, quartzite, chert and complex cherty iron-rich rocks. Their features are best explained by the pressure-solution theory of origin. Stylolite development causes loss of section, and in some limestones this may induce new structures in overlying strata. Dissolved calcite may precipitate and cement the limestone itself or nearby formations, and differential pressure-solution of calcite in dolomitic limestones can increase their proportion of dolomite. The potential importance of these phenomena should be considered in detailed investigations of limestone areas.

The origin of the quartz cement which makes many Western Australian sandstones too tight to be fluid reservoirs remains an enigma. Quartz cement in some sandstones elsewhere was apparently derived by pressure-solution of quartz grains, but this has not been established for Western Australian rocks examined.

Some stylolites in chert may be relicts of an earlier limestone fabric, whereas others occur in chert for which the hypothesis of primary deposition of silica is favoured. Even where replacement can be demonstrated, it may not be possible to decide if the stylolites are relicts.

Introduction

Definition

Stylolitic seams are defined by Pettijohn (1957) as surfaces marked by interlocking or mutual penetration of the two sides, with teeth-like projections on one side fitting into sockets on the other. They are far more common in limestones than in other rocks and are generally said to form by a process of pressure-solution. There has been controversy about their origin and even the derivation of the term, though it now seems agreed that the word ultimately came from *stylos,* a pillar or column (Pettijohn 1958).

Significance

Stylolitic seams were once considered to be sedimentary curiosities, but it is becoming increasingly appreciated that they are the results of processes that can be stratigraphically and economically important. Many authors have agreed that the formation of stylolites in limestones can lead to remarkable loss of section; some (Ramsden 1952, Dunnington 1954) have emphasized the role of stylolites in the accumulation of oil, and others (Ohle 1951, Towse 1957, C. W. Brown 1959, and Glover 1968), though differing in postulated mechanisms, have drawn attention to their role in concentrating dolomite in dolomitic limestones. It is likely that the loss of limestone section when abundant stylolites form can cause structural modification of overlying strata, and may release carbonate for the cementation of porous rocks elsewhere.

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Waldschmidt (1941), when investigating factors influencing migration of oil in the Rocky Mountains region, postulated a connection between the formation of interlocking grain boundaries and silicification in sandstones. Later, Heald (1955, 1956, 1959) also drew attention to the significance of pressure-solution in cementing sandstones. James (1951) used stylolites in deducing the petrogenesis of iron-rich rocks, and Blake and Roy (1949) used them in the structural interpretation of deformed rocks. The economic and petrogenetic significance attributed to some stylolites is sufficient justification for describing their occurrence in Western Australian sedimentary rocks, and for predicting where they may be expected.

Formation

The main dispute about stylolites has been whether they form in consolidated or unconsolidated sediments. The most ardent advocate of formation in unconsolidated sediments has been Shaub (1939, 1949, 1950, 1953, 1958), who postulated that narrow clay bands in calcareous muds form impermeable barriers to the upward movement of water. The mud below the clay remains saturated, whereas the mud above the clay becomes relatively dehydrated and contracts laterally, leading eventually to plastic flow of the underlying material at right angles to the bedding and an interlocking texture marked by an argillaceous seam. Dunnington (1954) effectively countered the contraction-pressure theory of Shaub with his attribution of a pressure-solution origin in consolidated rocks to many stylolitic fabrics. The pressure-solution theory, in Dunnington's words, "recognizes that hard rock is removed during the formation of stylolites, that the removal takes place by solution, with deposition of insoluble residues *in situ,* and that the solution is localized and directionally controlled by pressure." Dunnington's case for the post-consolidation development of stylolites where calcite veins are displaced and shells are truncated seems incontrovertible. The pressure-solution theory had been advocated earlier by Stockdale (1922, 1926, 1943), and although the precise mechanism of the pressure-solution process is not always agreed on, the ease with which the theory seems to account for most aspects of stylolites has led to its general acceptance by western geologists. Petrofabric analysis of stylolitic rocks has also been interpreted as supporting the pressure-solution theory (W. W. M. Brown 1959). Nevertheless, the view that stylolites form in unconsolidated rocks retains advocates (Prokopovich 1952, Rybakov 1959).

The pressure-solution theory of stylolite formation can apply only to consolidated or compacted material. Strong consolidation implies lithification, but not necessarily cementation (the occupation of pores by secondary minerals). If pressure-solution in porous rock is followed by nearby precipitation, the rock becomes cemented. Thus Waldschmidt (1941), Sloss and Feray (1948), and Heald (1959) proposed pressure-solution as a cause of cementation in sandstones, and Barret (1964) and Park and Schot (1968) concluded that it plays the same role in limestones. Other authors (Conybeare 1949, 1950; Herbert and Young 1957) emphasized the lateness of stylolites in some diagenetic sequences, and Park and Schot (1968) have accepted the possibility that some stylolites form after cementation. The process probably tends to begin in porous rocks, causing cementation, and continues in some after the elimination of most pore space, expelling almost all subsequently dissolved material. In this way, both intrastratal and interstratal cementation may be caused by pressure-solution in limestones or sandstones. On the other hand, some stylolites seem to have begun growth in rocks of very low porosity, such as volcanic rock and primary chert.

The surfaces of stylolitic seams are uneven, but most are parallel in a general way to bedding, and the pressure required to form them is apparently due mainly to load. Each seam indicates a loss of section at least equal to its amplitude, though Pettijohn (1957) pointed out that the loss may be far greater. Published estimates of the minimum loss of section demonstrated in different units include 40% (Stockdale 1926), 25% (Weller 1960) and 37% (Park and Amstutz 1968). Weller has also suggested that many clay seams in limestones have formed by concentration of insolubles without formation of interlocking surfaces. Barrett (1964) assumed a like origin for sand and clay seams in Oligocene calcarenites with a consequent volume loss of 4-16%. It is not impossible that some limestone units have disappeared entirely because of pressure-solution, but prospects of demonstrating this in specific instances are slight.

Records of stylolites in limestone, dolostone, marble, sandstone and quartzite are numerous. Stylolites are also reported from chert (Trefethen 1947), shale and conglomerate (Bushinskiy 1961), chert-siderite rocks (James 1951), carbonate-fluorite rocks (Amstutz and Park 1967), phosphorite, bauxite, anhydrite (Bushinskiy 1961), gypsum (Stockdale 1936, Bushinskiy 1961), sylvite (Bushinskiy 1961, Holwerda and Hutchinson 1968), barite (unpublished references cited by Park and Schot 1968), pyrite, arsenopyrite, zircon, chromite and rutile (Schidlowski and Turrnit 1966), rhyolite (Bloss 1954, Golding and Conolly 1960, 1962), welded tuff (Burmah and Riley 1955), pegmatite and quartz lenses (Bailly 1954), and asbestos (Males and Golding 1961). Trurnit (1967), who has listed many minerals affected by pressure solution, has been able to arrange them in a sequence according to pressure-solubility. A few stylolites cut across bedding (Blake and Roy 1949, Prouty 1952, Rigby 1953, Young 1953, Edgell 1964, Plate 2, Fig. 6). It is evident that, although Shaub's contraction-pressure theory cannot be disproved for some stylolites, it cannot explain those in non-sedimentary rocks or those transverse to bedding.

Stylolites in Western Australian Rocks

Limestones

There is no doubt that detailed examination of many otherwise fairly homogeneous Western Australian limestones will reveal stylolitic seams of quartz, clay minerals, limonite, carbonaceous material, graphite, bituminous material or combinations of these substances, for they commonly represent the insoluble residue of limestones after pressure-solution. Stylolites of this kind have been noted in fine-grained calcitic limestone from the Proterozoic Mt McRae Formation (Fig. 1), in fine-grained dolostone from the Proterozoic Duck Creek Dolomite (both from the West Pilbara area), and in Devonian limestones from the Fitzroy Trough.

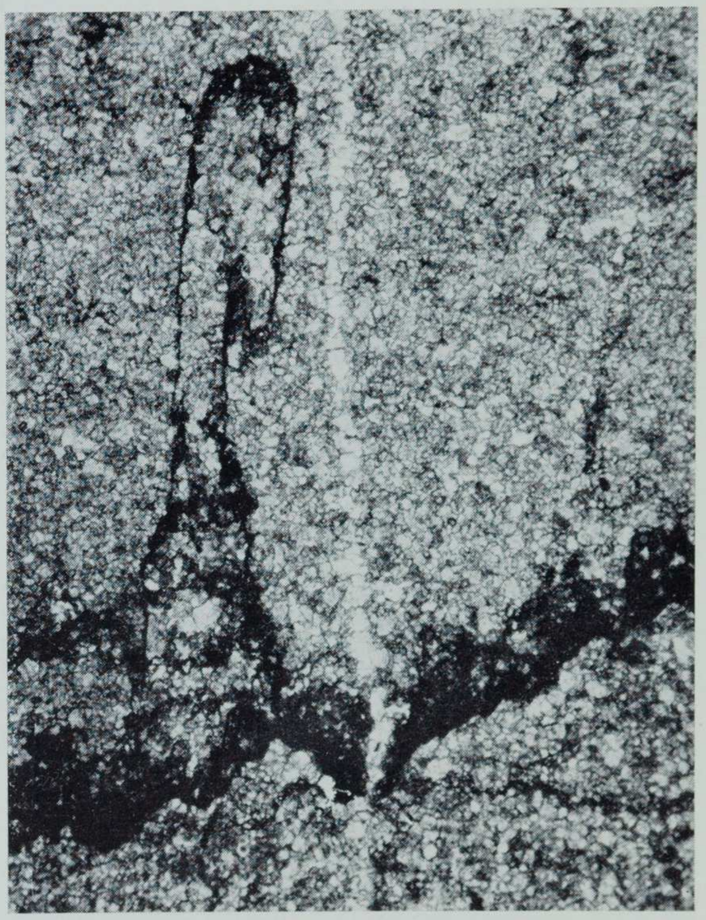

Figure 1.—Photomicrograph of stylolite in calcitic limestone from Proterozoic Mt McRae Formation, 386 feet 5 inches in core Y1, Yampire Gorge. The stylolite splits and coalesces, and is cut by a calcite vein. Plane polarized light. Width of field 2.5 mm.

More complex stylolites are likely to form in limestones containing two carbonate minerals, for one mineral may prove less soluble than the other, causing differential pressure-solution. For example, the fabric in parts of the Ordovician Thangoo Limestone from West Australian Petroleum's Roebuck Bay No. 1 Well in the Canning Basin, where dolomite caps most of the stylolite columns in the mainly calcitic limestone, indicates differential pressure-solution of calcite with respect to dolomite (Fig. 2). We can speculate that relative enrichment of dolomitic limestone in dolomite could, in extreme cases, form dolostone from dolomitic limestone.

The Thangoo Limestone in Roebuck Bay No. 1 comprises micrites, intrasparites, and pelsparites, some of which are highly dolomitized, and fine-grained dolostones of uncertain origin. It has been suggested elsewhere (Glover 1968) that the 646 feet interval of Thangoo Limestone intersected in this well is the remains of a formation that has lost at least 130 feet, and perhaps far more, by pressure-solution.

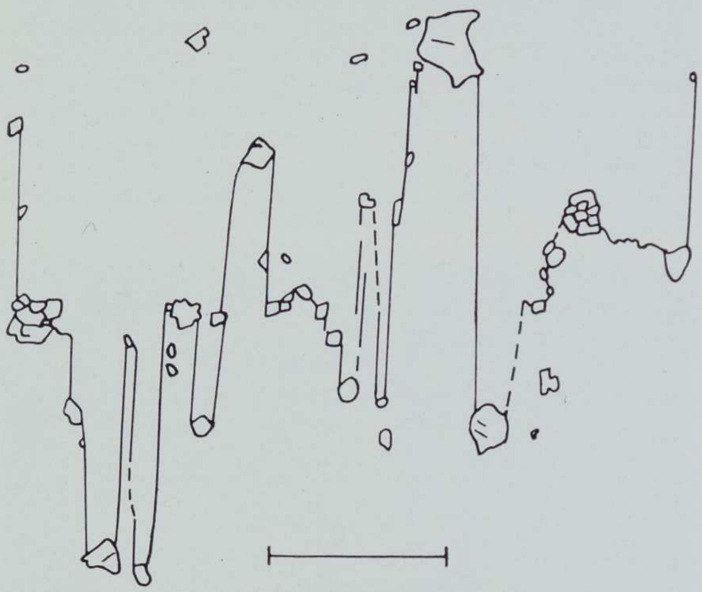

Figure 2.—Stylolite from intrasparite in Ordovician Thangoo Limestone, 3515-3522 feet, Roebuck Bay No. 1. Dolomite grains or aggregates occur at the ends of most columns, but are sparse elsewhere. A few grains show cleavage. Drawn to scale from thin section. The horizontal line represents 1 mm.

Stylolitic boundaries are fairly common between dolomitic and calcitic portions of Palaeozoic dolomitic limestones. Parts of the Thangoo Limestone in cores from West Australian Petroleum's Goldwyer No. 1 Well illustrate this feature. The bore-core in Figure 3 is made up of interbedded light grey, silty, fine-grained calcitic limestone bands of irregular thickness and thinner, dark grey, silty dolomite bands. Some black stylolitic seams of silty clay are found within the calcareous bands, but most seams form well-defined boundaries between the calcareous and dolomitic bands. A traverse along a thin section of the rock revealed 41 mm of silty calcitic limestone, 16 mm of silty dolomite, and 2 mm of silty clay. The concentration of quartz silt in the clay is about 15 times greater than in the calcitic limestone so that if the clay is a residue of the pressure-solution of calcite, it represents 30 mm of calcitic limestone. Thus, if this rock developed by differential pressure-solution of calcite in a consolidated limestone consisting of banded, silty, slightly argillaceous calcitic limestone, and dolomite, over 30% of its original length in the part sectioned was lost.

The possibility that some impurities promote solution in limestones must be borne in mind, for no simple, direct relationship between depth of burial and loss of volume by pressure-solution seems to have been established. Despite this uncertainty, it is evident from the literature and from the above examples, that section loss of 5-40% is not exceptional over small intervals. Losses of this order in thick limestone formations would have to be accommodated by buckling or collapse in formations above.

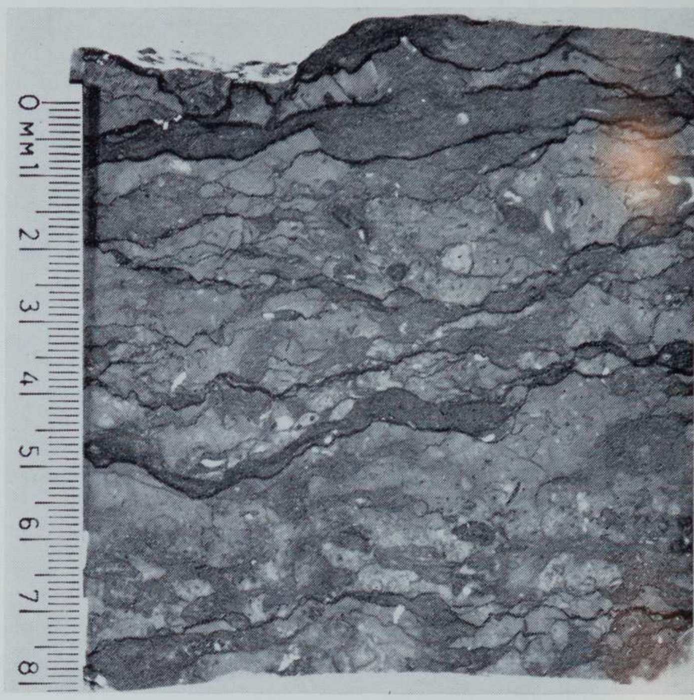

Figure 3.—Interbedded silty dolomite (dark grey) and silty calcitic limestone (light grey) in Ordovician Thangoo Limestone, 3613-3629 feet, Goldwyer No. 1. Black stylolitic seams commonly form boundaries between dolomite and calcite.

Sandstones

Macrostylolites are less common in sandstones and quartzites than in limestones, and appear to be associated with much smaller loss of section. They have been observed in Western Australian rocks but do not seem to have been recorded. In view of the numerous accounts of their occurrence in North America, it is unlikely that they are as rare here as the literature would suggest. The stylolite illustrated in Figure 4 has an amplitude of about four cm and is in a silicified medium-grained quartz sandstone or impure orthoquartzite containing intergranular patches of microcrystalline quartz and less common patches of limonitic clay. The clastic cores of many quartz grains are visible under the microscope. The stylolite seam is about one mm thick, is composed of white and red argillaceous material, and is approximately parallel to the bedding. The specimen is a boulder from the Upper Devonian Willaraddie Formation, near Gneudna Well, in the Carnarvon Basin.

It has been suggested on empirical grounds by Heald (1959) that the stress required to form stylolites in sandstones may not be especially high because the clay minerals, carbonaceous minerals and iron-bearing minerals constituting the stylolitic seams were originally partings in the rock and promoted the solution. Thomson (1959) proposed that clay seams can

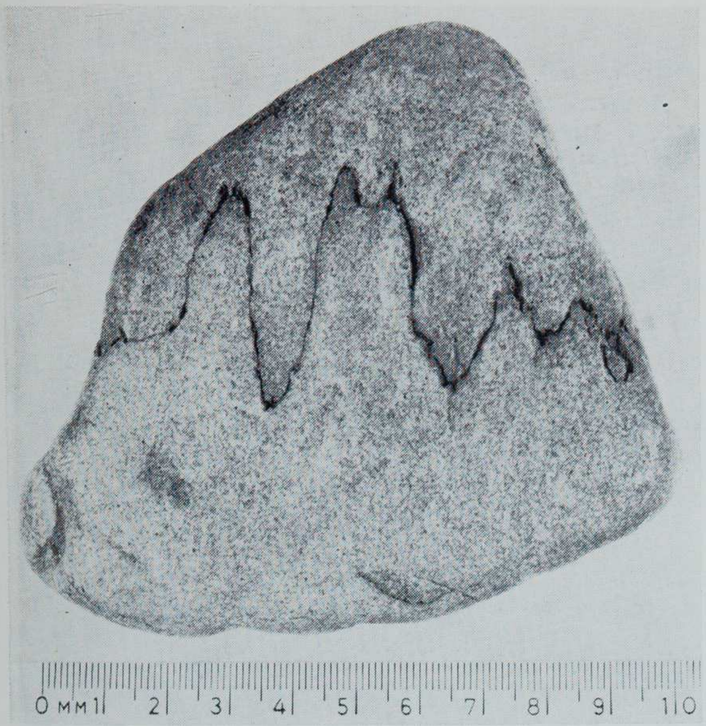

Figure 4.—Stylolite in silicified medium-grained sandstone of the Upper Devonian Willaraddie Formation.

increase the pH of solutions and promote solution of silica and subsequently Lerbeckmo and Platt (1962) suggested a mechanism involving carbon and iron compounds in seams which could also locally increase pH. The lithology of the stylolitic quartzite described above is compatible with the hypotheses of Heald and Thomson.

Many standstones, otherwise regarded as potential reservoir beds for hydrocarbons in Western Australia, are tight because of silicification, and it is important to establish how they were silicified. Waldschmidt's studies of sandstones in the Rocky Mountains region (Waldschmidt 1941) indicated that pressure-solution caused interlocking boundaries between grains, and was accompanied by contemporaneous precipitation in adjacent pores. Heald (1956), after studying the Simpson and St Peter Sandstones, also accepted pressure-solution at grain contacts as the source of most dissolved silica, but assumed that precipitation was not necessarily local. There are sutured grain contacts in the Enokurra Sandstone (Glover 1963), but they are rare in other silicified sandstones examined to date. Most quartz cement in bore-cores of silicified standstone has not been derived *in situ*, and the contribution of pressure-solution to its origin can only be assessed by comprehensive lateral studies of formations. Some solution and precipitation is likely to be practically independent of pressure, being due rather to changes in pH of circulating waters, or to other influences. The magnitude of silicification in replacement cherts, for example, seems to exclude pressure-solution as the only source of precipitated silica. The literature on silicification is extensive and will not be reviewed here: a recent summary has been presented by Fairbridge (1967).

Chert

Macrostylolites and microstylolites in the Coomberdale Chert were described and figured by Logan and Chase in 1956 in an unpublished B.Sc. Honours thesis in the Department of Geology, University of Western Australia. In a published account (Logan and Chase 1961) the stylolites were not mentioned, but it was demonstrated that the chert was a silicified limestone grading into dolomite and containing many relicts of limestone fabric including ooliths, carbonate rhombs, and fossils. It is not known if the stylolites are also relicts of the limestone fabric, or if they formed in the chert. A microstylolite from the Coomberdale Chert is illustrated in Figure 5.

Figure 5.—Photomicrograph of stylolite in Coomberdale Chert (probably Proterozoic) from Kiaka Cliff, 9 miles north of Moora. Plane polarized light. Width of field 2.8 mm.

Cherty, iron-rich rocks

A stylolite from the S11 macroband of the Dales Gorge Member of the Brockman Iron Formation at a depth of 385 feet 6 inches in bore-hole 51 is illustrated in Figure 6 (bore-hole 51 is shown on the geological map of Wittenoom Gorge, which is Plate 6 of *Geol. Surv. W. Aust. Bull.* **119**). The stylolite has an amplitude of about one centimetre, and separates banded chert-stilpnomelane rock containing siderite and accessory pyrite from siderite rock, also containing accessory pyrite. Black material of uncertain composition is concentrated along the stylolite in the siderite rock, and pyrite is more abundant in the dark area. This stylolite resembles those described by

James (1951) in chert-siderite rocks of the iron formation from Michigan, where they make up part of the fabric from which a primary origin for the chert has been inferred.

Figure 6.—Photomicrograph of part of S11 macroband of Dales Gorge Member, 385 feet 6 inches, bore-hole 51. Stylolite between dark impure siderite (top) and white siderite in banded siderite-chert-stilpnomelane rock (bottom). White lenses in grey, flaky stilpnomelane are chert. Plane polarized light. Width of field 1.7 mm.

Contorted seams or microstructures from the S13 macroband of the Dales Gorge Member at 318 feet 5 inches in bore-hole 51 are shown in Figure 7. These seams consist of chert, stilpnomelane and siderite, with a concentration of siderite along their margins, and form irregular boundaries with the otherwise euhedral ankerite crystals in the surrounding chert. Their undulose form, and the way in which they cut ankerite grains, suggest that they are at least partly due to pressure-solution. If the chert is primary the seams may represent thin layers of impurity which have promoted pressure-solution in the way envisaged for quartzites by Thompson (1959) and Lerbeckmo and Platt (1962). If the chert has replaced limestone, the seams could be relict stylolites, for which a rather complex sequence may be invoked, as follows:

(1) formation of impure limestone containing replacement euhedra of siderite and ankerite.

(2) differential pressure-solution of calcite concentrating iron-rich carbonates along the seams, and partly dissolving ankerite.

(3) preferential silicification of calcite, preceded or followed by reconstitution of impurities to stilpnomelane.

A vertical stylolite has been figured in a siliceous discoidal body interpreted by Edgell as the silicified alga *Collenia brockmani* n. sp., in the Brockman Iron Formation (Edgell 1964, Plate 2, Fig. 6). The stylolite was presumably formed by lateral pressure, but the exact mechanism of its origin is obscure.

Figure 7.—Photomicrograph of part of S13 macroband of Dales Gorge Member, 318 feet 5 inches, bore-hole 51. Large dark grains are ankerite, small dark grains are siderite, white areas are chert. Grey seams, apparently of stylolitic origin, consist of chert and stilpnomelane, with siderite concentrated along margins. Plane polarized light. Width of field 2.1 mm.

Conclusions

Stylolites are not uncommon in limestones, and their formation can cause significant loss of section, changes in lithology and possibly changes in the structure of overlying rocks. Their potential influence should be borne in mind during detailed surveys of limestone areas. On the other hand, although stylolites as known in sandstones and quartzites, there has been no compelling evidence that most of the silicification of sandstones in Western Australia, with its adverse effect on their petroleum prospects, has been related to pressure-solution. Stylolites have also been recorded in chert and iron-rich cherty rocks of complex lithology, and preliminary examination suggests that these petrogenetically significant phenomena will be reported more frequently. However, there seem at present to be few effective criteria for deciding if stylolites in replacement cherts are relict limestone structures.

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